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Study of trap depth characteristics in ZnTe thin films based on photocurrent decay

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Abstract : Photocurrent decay characteristics were studied in zinc telluride thin films deposited by thermal evaporation on glass substrates held at room temperature (290K). Two different decay times of photocurrent were found which correspond to two distinct trap depths The trap depths were found to increase with ambient temperature and intensity of white light illumination The estimated trap depths range from 0.26 eV to 0.61 eV.

Keywords : Zinc telluride thin film, trap depths, photocurrent decay.

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Zinc telluride is a technologically important member of II-VI compounds for its potential use in a variety of solid state devices such as photo detector, light emitting diodes and solar cells [1,2] Recent study on ZnTe also reveals that it can be used for optoelectronic detection of THz radiation[3]. For such device applications, thin film form of the material is particularly useful. Thin films of zinc telluride grown at room temperature on glass substrates are found to be polycrystalline in nature[4]. The optoelectronic properties of these polycrystalline thin films are greatly influenced by both native and foreign imperfections. Native defects such as various traps having energies in the range of 0.15 eV to 0.8 eV can cause a considerable change in electrical and optical properties of the semiconductor thin films[5,6]. These defects characterize the electronic properties of the material, because they give rise to charged centres acting as donors or acceptors[7]. In view of the relative lack of information concerning trapping spectrum in thermally evaporated ZnTe thin films, an attempt has been made to study the characteristics of the various traps from the analysis of photocurrent decay under different conditions of illumination level and ambient temperatures.

Thin films of zinc telluride were deposited by thermal evaporation technique with the help of a Hind High Vacuum coating unit (HINDHIVAC 12A4) at a vacuum 10^{-6} Torr., on suitably cleaned glass substrates held at room temperature. Pure (99.999%) bulk ZnTe samples obtained from Koch Light Lab.,(U.K.) were used as the source material.

For getting ohmic contacts, coplanar electrodes of aluminium separated by a gap of 7mm were vacuum evaporated on the substrates (10mm × 15mm) on which the films were then deposited. Thus, a gap type cell configuration was obtained. Thickness of the deposited films were measured with the help of the multiple beam interferometry method. Photocurrent was measured by using an ECIL electrometer amplifier of high input impedance (~10^{14} ohm and higher). Light intensity was measured with the help of a sensitive APLAB luxmeter. The electrical and optical measurements of the sample were taken keeping the sample properly suspended inside a continuously evacuated (10^{-2}Torr.) glass jacket.

External noise is particularly disturbing in these thin film samples having resistance in the range of 10^{10} to 10^{12} ohm. In order to minimize the noise level, all the electrical measurements were taken by keeping the entire experimental setup (including the observer) in a suitable Faraday cage.

The trap depths were calculated by using the simple decay law

$$I_t = I_0 \exp(-pt), \qquad (1)$$

where p is the probability of escape of an electron from the trap per second and is given by [8]

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$$p = S \exp(-E/kT). \quad (2)$$

Using these two relations, we get the expression

$$E = kT\left[\ln S - \ln\{\ln(I_0/I_t\right. \quad (3)$$

where E is the trap depth for electrons below the bottom of the conduction band, k is the Boltzmann constant, T is the ambient temperature in K, I_0 is the photocurrent at the termination of illumination, I_t is the photocurrent at any subsequent time t after the termination of illumination and S is the frequency factor defined in terms of number per second that the quanta from the lattice vibrations (phonons) attempt to eject the electron from the trap, multiplied by the probability of transition of the ejected electron to the conduction band[9].

The probability of an electron escaping from a trap of depth E and cross section for its capture S_t at a temperature T is given by [10]

$$p = N_{eff} \nu_{th} S_t . \exp(-E/kT), \quad (4)$$

where N_{eff} is the effective density of states in the conduction band and ν_{th} is the thermal velocity of the electrons. Here, the product $N_{eff}\ \nu_{th}\ S_t$ represents the frequency factor S. For finding S, the values of N_{eff}, ν_{th} and S_t were calculated separately. N_{eff} was calculated from the conductivity data by using the relation $n = \sigma/e\mu$ [11], where σ is the conductivity evaluated from the experimental data of the current I_0. We made a simplifying assumption that at comparatively low temperatures the number of occupied energy levels in the conduction band *i.e.* n is identical with N_{eff}. μ is the mobility of the electrons in ZnTe. Its value was taken to be 340 $cm^2\ V^{-1}\ sec^{-1}$ at temperature 300 K[12]. The thermal velocity ν_{th} of an electron was calculated at different ambient temperatures by using the relation $\nu_{th} = (2kT/m^*)^{1/2}$, where m* is the effective mass of an electron which was taken to be $0.2m_e$[13]. The capture cross section is given by

$$S_t = \pi r^2, \quad (5)$$

where r is the radius of the capture centre. It was evaluated by putting the Coulomb energy of interaction of an electron with the corresponding trap equal to the thermal energy of the electron at temperature T [14]. In other words

$$e^2/r\varepsilon = kT, \quad (6)$$

where ε is the dielectric constant of ZnTe. Using r from relation (6) in (5), we get

$$S_t = \pi e^4/k^2T^2\varepsilon^2. \quad (7)$$

At 300 K, $S_t \approx 10^{-10}/\varepsilon^2\ cm^2$. The value of the dielectric constant ε of ZnTe at low frequency was taken to be 7.4 [13]. Hence, S_t at 300K was found to be equal to $1.83 \times 10^{-12}\ cm^2$. This is seen to be the largest value of capture cross section for electrons[14]. It may be noted that in general, the capture cross sections for the electrons are reported to be in the range from 10^{-12} to 10^{-22}[14]. Using the relation $S = N_{eff}\nu_{th}S_t$, the frequency factor S at different ambient conditions were evaluated. The different values of S are shown in the Table 1.

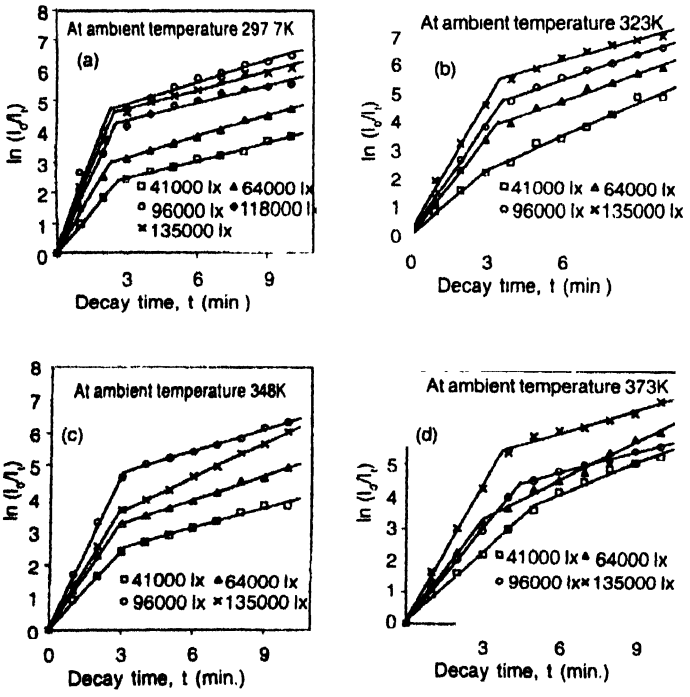

Figure 1. Plots of $\ln(I_0/I_t)$ *versus* photocurrent decay time (t) at different intensity of illumination and ambient temperatures.

It is seen from the Table 1 that there is a gradual increase in the value of S with ambient temperature as well as with intensity of illumination. Using these values of S and p [$=\ln(I_0/I_t)/t$] evaluated from the slopes of $\ln(I_0/I_t)$ *versus* t plots [Figure 1 (a),(b),(c) and (d)] in the relation (3), trap depths at different ambient conditions were calculated. From Figure 1 it is observed that there exist two different slopes. Slope 1 and 2 corresponds to decay times 0 to 3 min., and 3 to 10 min., respectively. From the evaluated values of E, it is seen that there is a quasi continuous distribution of trap levels[11] (0.26eV to 0.61eV) below the conduction band. It may be noted that photocurrent in these thin films was found to obey a sublinear relationship with the intensity of illumination[5] which could be explained on the basis of defect-controlled photoconductivity mechanism.

The estimated trap levels in the present work are likely to be the defect levels as mentioned. The experimental value of the band edge calculated from $\ln\sigma$ *versus* $10^3/T$ plots as well as from the dominant peak of spectral response characteristics was found to be 1.59eV. This corresponds to an energy level at 0.67eV (2.26eV – 1.59eV) below the bottom of the conduction band. Which is clearly a donor level.

The existence of the observed trap levels may be interpreted as follows. From the spectral response characteristics, along with the main photocurrent peak at 1.59eV and two smaller peaks at 1.76eV and 1.92eV were also observed. By absorbing energy from the illuminating radiation electrons are excited from the

Table 1. *Calculated values of conductivity (σ), effective density of states (N_{eff}) frequency factor(S) and trap depth(E) for different intensity of illumination and ambient temperatures*

Intensity of illumination	Ambient temperature (290.7K)					Ambient temperature (323K)					Ambient temperature (348K)					Ambient temperature (373K)				
	σ	N_{eff}	S	E(ev)		σ	N_{eff}	S	E(ev)		σ	N_{eff}	S	E(ev)		σ	N_{eff}	S	E(ev)	
(lux)	(ohm cm)$^{-1}$ in 10^{-7}	(cm)$^{-3}$ in 10^{9}	sec^{-1} in 10^{5}	E_1	E_2	(ohm cm)$^{-1}$ in 10^{-6}	(cm)$^{-3}$ in 10^{10}	sec^{-1} in 10^{6}	E_1	E_2	(ohm cm)$^{-1}$ in 10^{-6}	(cm)$^{-3}$ in 10^{10}	sec^{-1} in 10^{5}	E_1	E_2	(ohm cm)$^{-1}$ in 10^{-5}	(cm)$^{-3}$ in 10^{11}	sec^{-1} in 10^{7}	E_1	E_2
41000	0.55	1.31	0.39	0.26	0.30	0.82	1.52	0 61	0.38	0 41	1.71	3 15	0.75	0.41	0.46	0.74	1.36	0.59	0.51	0.53
64000	0.99	1.81	0.70	0.27	0.31	1.30	2 39	0.97	0.38	0 42	3.17	5.82	1.38	0.42	0 47	1.24	2.27	0.96	0.52	0.55
96000	3.01	5.53	2.13	0 29	0.34	3.04	5 59	2.27	0.40	0 44	7 92	14.56	3.46	0.45	0.50	1.87	3.44	1.50	0.53	0.57
118000	6.34	11.65	4.47	0.32	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
135000	14.00	25.74	9.88	0.34	0.38	6.37	11 71	4.74	0.42	0.47	13.6	25.04	5.94	0.46	0 51	3.80	6.99	3.04	0.54	0.61

σ : Photoconductivity of the sample just before the termination of illumination, N_{eff} : Effective density of states in the conduction band.
S : Frequency factor, E : Trap depth, E_1 : Trap depth evaluated from slope 1, E_2 : Trap depth evaluated from slope 2.

valence band to the energy levels at 1.59eV, 1.76eV, 1.92eV corresponding to the wavelengths of 781nm, 705nm, 647nm respectively, below the conduction band bottom where they are captured by a high density of capture centres existing at these energies. The capture cross-section being the largest (*i.e.* 1.83×10^{-12} cm^2), the probability of capture of electrons is expected to be very high. The possibility of existence of such high density of levels finds support from the reported results of deep centre electroluminescence studies made in Zn Te samples [15]. They observed that within the range of wavelengths 751 – 795 nm maximum electroluminescence occurred in ZnTe. It may be noted that the experimentally observed wavelength of the main photocurrent peak at 781nm (≈ 1.59eV) is well covered in this work, within the quoted range of wavelengths for maximum electroluminescence.

The electrons captured in these centres become free at the end of their respective life times in the capture centres. These electrons then take part in the photoconduction process under the influence of the applied bias and illuminating radiation. However, there is a high probability that some of the freed electrons may be recaptured by some capture centres giving a probable distribution of trap depths, which are indicated in Table 1.

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